Palaeoclimate reconstructions from the Antarctic Peninsula: Diatoms as indicators of Holocene environmental change

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Summary Fossil diatom assemblages preserved in marine sediments from the Antarctic Peninsula (AP) provide information with which to determine palaeoceanographic and palaeoclimatic variability for the Holocene. The use of diatoms as a proxy is based on the response of species to limiting factors, tracking changes in surface water mass characteristics and sea-ice extent. Through detailed comparison of AP sediment cores spatially and temporally, this project aims to reconstruct changes in water mass circulation on the continental shelf, fluctuations in sea-ice extent and ice shelf collapse events. A key question is: were such events peninsula-wide and synchronous during the Holocene?

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Introduction - why Antarctica and why past climate?

The Antarctic Peninsula (AP) is one of the fastest warming regions on Earth, with meteorological records showing increased temperatures of 3.7 ± 1.7 ºC during the last century (Vaughan et al., 2003). This temperature increase is more than five times the global mean (0.6 ± 0.2 ºC; Houghton et al., 2001). A key question facing scientists and policy makers is whether this warming is part of the natural variability in the climate system or are humans upsetting the balance in this delicate system. When looking to the future, it is crucial to understand the periodicity, amplitude and rate of climate changes in the past.

Palaeoclimate reconstructions for the Holocene show that global temperatures are likely to have been far less variable than during the last glacial period and subsequent transition (Folland et al., 2001). However, excursions do exist in the relatively stable Holocene period, recording rapid and significant climate change in both hemispheres (summaries of globally distributed palaeoclimate records can be found in Domack and Mayewski, 1999; Mayewski et al., 2004). Focusing on the AP region, palaeoclimate records from ice cores (Masson et al., 2000), lake sediments (Bentley et al., 2005; Smith et al., 2007) and marine sediments (Leventer et al., 1996; Pudsey and Evans, 2001; Taylor et al., 2001) document several, often rapid Holocene temperature excursions.

The world-wide occurrence of Holocene climatic events, with similar character and frequency, points to primary astronomical forcing, with several studies further observing an overprinted solar forcing signal of a 200 yr rhythm, related to reduced sunspot activity (Bárcena et al., 2006; Leventer et al., 1996). The oceans are also an important component of the complex climate system, as they provide a mechanism for transmission of climate anomalies on both global and regional spatial scales. Antarctica, and specifically the Southern Ocean, are key features of global thermohaline circulation. Lying in the centre of the this circulation, the Southern Ocean connects each of the ocean basins, with Antarctic water masses being traced to 40ºN in the northern hemisphere (Bigg, 1996) and around the globe. The extent of Antarctic sea-ice, migrations of the Polar Front and water mass interactions will clearly influence the world's oceans (deep and bottom water production, thermohaline circulation and productivity) and climate (position of the westerly wind belt, equator-pole gradient and albedo effects). Reorganisation of the global circulation clearly has important implications for the timing and patterns of climate change and it is crucial to understand the processes happening both today and in the past.

Project aims

The main aim of this research project is to address questions on natural variability in the Earth's system through the Holocene, specifically links between the ocean and terrestrial environments. Focus will be placed on reconstructing changes in water mass circulation on the continental shelves of the AP, sea-ice extent and ice shelf collapse events, both spatially and temporally. Such palaeoclimate reconstructions will be achieved using fossil diatom assemblages preserved in marine sediments from a range of continental shelf settings along the AP. Sediment and diatom records will be compared between marine locations and with adjacent terrestrial records, providing valuable information on spatial variability (propagation of climate events), temporal trends (leads and lags) and consequently enabling forcing mechanisms to be assigned to the observed climatic change. This type of study will perform a vital role in assessing the palaeoclimatic history of the AP in relation to global Holocene climate events (Figure 1).

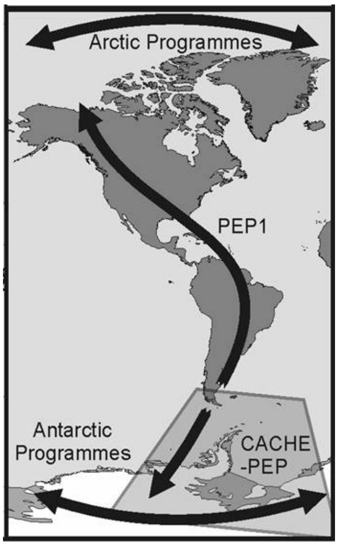


Figure 1.
This project forms part of a larger science programme run by the British Antarctic Survey "Climate and Chemistry (CACHE): Forcings, Feedbacks and Phasings in the Earth System", which places particular emphasis on extending the Americas palaeoclimate transect through the AP to the pole (CACHE-PEP).

Methods

Palaeoclimatic and environmental reconstructions are being achieved through detailed analysis of marine sediment cores from several locations along the AP. To date, three British Antarctic Survey cores have been logged and sampled at high resolution, regularly spaced intervals (<10 cm). The biogenic component of the sediment is studied to show changes in fossil diatom assemblages. Diatoms are unicellular, eukaryotic, photosynthetic micro-organisms that secrete a siliceous cell wall. In the marine realm, they are extremely common in high latitudes, particularly the Southern Ocean. Their use as proxies is based on the response of species to limiting factors, such as light levels and nutrient availability, tracking changes in water characteristics and sea-ice extent.

Results

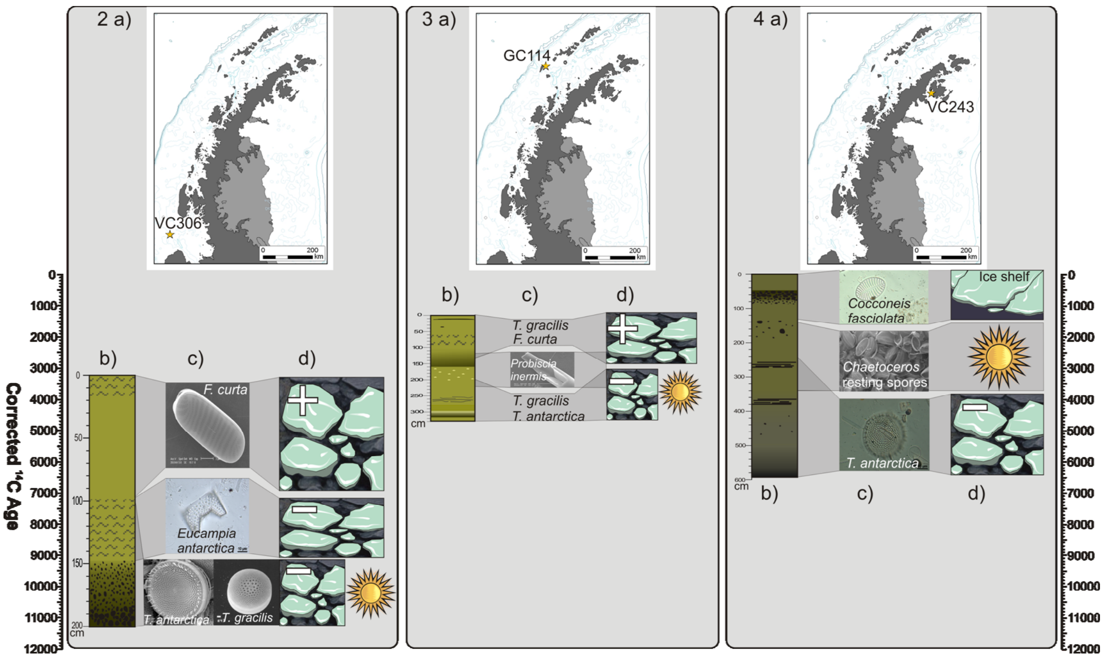
A suite of three cores, when stacked together, provide a full record of Holocene environmental change along the AP. Dramatic and significant fluctuations in terrigenous and biogenic inputs are evident, together with associated variations in the fossil diatom assemblages. Figures 2-7 show data for cores VC306 (Marguerite Bay, western AP), GC114 (Bransfield Strait, western AP) and VC243 (Prince Gustav Channel, eastern AP) respectively. The cores have been ^{14}C-dated by accelerator mass spectrometry on the acid-insoluble organic carbon fraction. Each of the cores yield good age-depth progression, although high core-top ages were found throughout. This is not uncommon in the Southern Ocean, due to the large and regionally variable marine reservoir effect (Berkman et al., 1998; Domack et al., 2001).

Preliminary conclusions

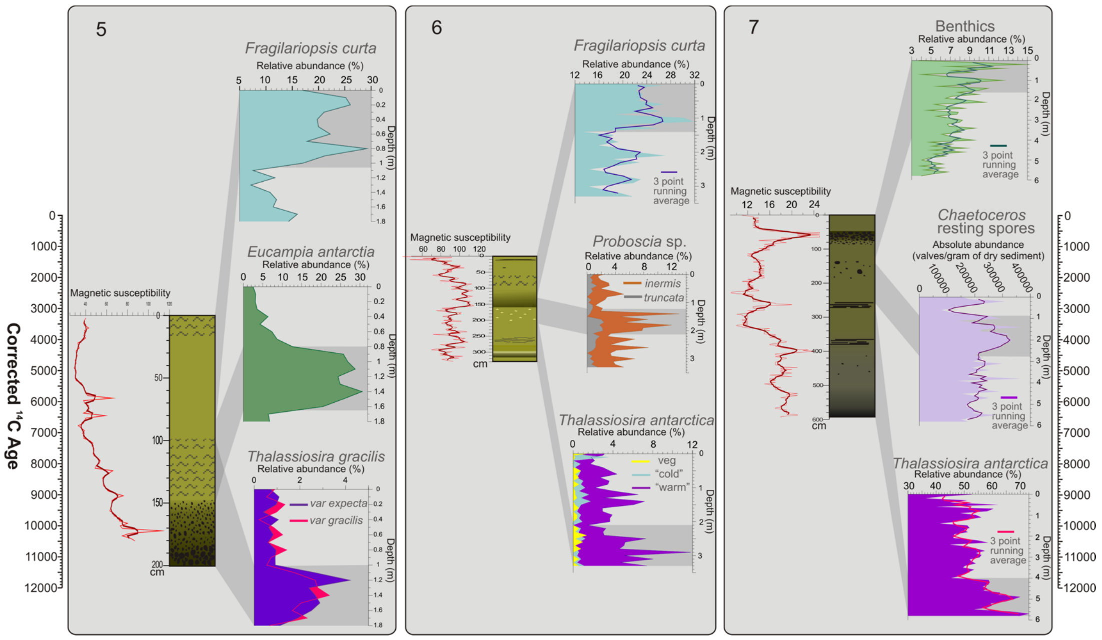
- Significant changes in primary productivity and sediment diatom assemblages are recorded in marine sediments through the Holocene
- These changes are likely to be driven by fluctuations in sea-ice conditions (its extent and seasonal duration) and surface water stability and stratification, with linked teleconnections between the cryosphere and atmosphere system
- The general pattern exhibited in cores VC306, GC114 and VC243 is broadly consistent with published marine datasets for the AP
- There is some discrepancy with the timing of certain events and the predicted environmental conditions
- **Are these artefacts associated with the dating problem of Antarctic marine sediments, or true features – climatic events along the AP were not synchronous during the Holocene?**

Future work

The chronology and marine reservoir correction for these marine cores needs attention. This is being addressed through supplementary geomagnetic palaeointensity dating methods. Other future plans involve the augmentation of the diatom records with additional proxies, particularly the biomarker signal preserved in the sediment. Pigment analysis is a commonly used technique for Quaternary lacustrine sediments in Antarctica (Hodgson et al., 2004; Squier et al., 2005), but not one that has been applied extensively in the marine realm. This is an exciting new area of research with real potential to link marine diatom records to terrestrial records of climatic change, hence integrate results across ocean-atmosphere system.



Figures 2, 3 and 4.
Composite data for cores VC306, GC114 and VC243 respectively. In Figures 2, 3 and 4: a) location of the core site; b) sedimentary log, which is positioned vertically on the page with reference to the time period the core spans; c) diatom photos (SEM and light microscope) showing diatom species of interest at different core depths (see Figures 5, 6 and 7); d) environmental reconstructions based on the sediment characteristics, magnetic susceptibility and diatom assemblages – open ocean conditions (sea-ice and sun), hypsithermal (sun), moderate sea-ice influence (sea-ice with negative symbol), heavy sea-ice influence (sea-ice with positive symbol) and floating ice shelf (ice shelf).
A reservoir correction of 6000 yr has been applied to VC243 and 1300 yr to GC114 and VC306.



Figures 5, 6 and 7.
Magnetic susceptibility curves, together with diatom relative and absolute abundance plots for cores VC306, GC114 and VC243 respectively. The diatom species highlighted at different core depths are not necessarily those exhibiting the highest abundances; those showing interesting patterns have also been chosen.

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